Altering Condensate Levels in Tobacco Smoke by Genetic Techniques*

by

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INTRODUCTION

Lower levels of condensate in cigarette smoke are being sought in various ways. Manufacturers can lower condensate but most of the methods used lower smoke nicotine and other smoke constituents simultaneously. Tobacco breeders are attempting to develop lines of tobacco whose cured leaf, upon pyrolysis, delivers less condensate in the smoke. Condensate is defined by the Federal Trade Commission (FTC) as total particulate matter collected on a standard Cambridge filter pad, after cigarettes have been smoked under specific conditions, minus nicotine and water. Condensate consists of many constituents and would appear to be difficult to change through genetic manipulations. Russell (11) suggested that we should aim toward lowering the yield of constituents such as condensate, carbon monoxide and others, without a concomitant lowering of nicotine. According to his suggestion, if this were accomplished the smoker would not consume more cigarettes to compensate for the low delivery of nicotine from low-condensate — low-nicotine cigarettes. Hence the condensate : nicotine ratio may be important in developing lines of tobacco that will deliver lower levels of condensate on pyrolysis. It has come to the attention of the authors that Russell and other investigators have somewhat changed their viewpoint on reducing condensate but not nicotine when they found that cigarettes, whose smoke showed a condensate to nicotine ratio less than 8 or 9, were rejected by consumers.

The purpose of this paper was to review the research on breeding for varying levels of condensate delivery, to present data from our own research, and to make suggestions for future attempts to develop tobaccos that de-

liver low condensate or that deliver smoke with a lower condensate : nicotine ratio.

Matzinger and Wernsman (7) studied certain smoke constituents delivered by a synthetic population of eight commercial cultivars of flue-cured tobacco. They showed significant genetic variations for cigarette weight, total alkaloids, puff/cigarette, wet total particulate matter (WTPM)/cigarette, and WTPM/puff. WTPM ranged from 25.2 to 36.6 mg/cigarette. They concluded that changes in total particulate matter (TPM) could be accomplished by breeding.

In attempting to develop lines of tobacco that yield low condensate, a large number of samples have to be assayed. This is difficult with the FTC condensate method because it requires samples which contain relatively large quantities of tobacco. Long and Wilson (6) described a procedure to estimate the particulate matter of cigarettes by pyrolyzing a 1 gram sample of tobacco. Therefore, by using the particulate matter index (PMI) technique, it is possible to analyze a large number of samples. Wernsman et al. (13) reported that PMI of 120 random F_3 lines from a Hicks × Coker 139 F_1 ranged from 174 to 226 mg/g. Estimated PMI reduction in the next generation, obtained by selecting the lowest 8.3 % of lines in the population, was 10.2 mg/g or 5.1 % of the population mean. Later, Matzinger et al. (8) reported that selection of PMI within a black shank-resistant synthetic population for reduced particulate matter in tobacco smoke was effective in obtaining a population which produced 14.3 % less PMI after three cycles of recurrent mass selection. This selection also lowered FTC condensate, but to a lesser extent. They also concluded from their study that selection for lower PMI would also lower leaf and smoke nicotine. Preliminary results indicate that selection for higher levels of nicotine and lower PMI can be accomplished if selections for both constituents are made concomitantly.

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Davis et al. (3) compared the PMI to cigarette condensate values for certain Burley tobacco genotypes and found that the ranking of genotypes was not the same for both methods; thus the two methods may not be comparable.

Data from experiments conducted at Oxford, N. C., in a program to develop tobaccos with lower condensate delivery, are presented in this paper.

MATERIALS AND METHODS

Cigarette Fabrication and Condensate Collection

After the tobacco was flue-cured, all of the primings from a plant were combined so each sample represented all of the tobacco produced on the plant. The tobacco was stemmed and the lamina made into 85 mm non-filter cigarettes. The cigarettes were selected for weight and constant draw pressure (7.5 cm Hg) at a flow rate of 17.5 cm³/s and kept at a constant relative humidity, 60%, and temperature, 23.9°C. The weights of the cigarettes varied among the samples; however, the weights of all cigarettes within a sample were constant. For each sample, 40 cigarettes were smoked on a 20-port Phipps and Bird smoking machine*, under standard conditions, to a 23 mm butt length as described by Pillsbury et al. (9) and the wet particulate matter was collected on 10 Cambridge filters (4 cigarettes per filter).

Cigarette Characterization

Data on a cigarette basis were obtained for weight, total particulate matter, nicotine, water, and puff count. Condensate delivery values per cigarette were calculated by subtracting nicotine and water from total particulate matter. The condensate/g of tobacco smoked was based on the amount of tobacco in the 62 mm portion of the cigarette actually smoked. Water and nicotine in total particulate matter were determined by the methods of Watson et al. (12) and Randolph (10), respectively.

Procedure for Particulate Matter Index (PMI) Determination

The procedure for PMI determination was a modification of that reported by Long and Wilson (6). The cured leaf was stemmed, dried for approximately 48 h at 65°C, and conditioned at approximately 21°C and 60% relative humidity for grinding. The samples were ground in a Wiley Mill* through a 2 mm screen. The ground samples were sieved through two screens: a coarse screen with an 850-micron mesh and a fine screen with a 500-micron mesh. The tobacco passing through the coarse screen and retained on the fine screen was used for the PMI determination. The ground and sized samples were brought to moisture equilibrium at 21.1°C and 60%

relative humidity in a constant temperature—relative humidity room. A 1 g sample of tobacco was placed in a Pyrex combustion tube. A pre-weighed Cambridge filter holder and pad were attached to the combustion tube and connected to a vacuum. The combustion tube was placed in a furnace at 620°C. The Cambridge filter holder and pad were reweighed and the weight increase following pyrolysis was used as the PMI. Duplicate particulate matter indices (PMI) were determined for each sample. The remaining tobacco from each sample was redried, reground and analyzed for total alkaloids by the Griffith procedure (4).

RESULTS AND DISCUSSION

Data are presented by experiments because it is invalid to compare data from one experiment with another since condensate and nicotine deliveries are considerably altered by the weather and cultural conditions to which the tobaccos were exposed.

Condensate Delivery Levels from U. S. Flue-cured cultivars

Samples of tobacco cultivars from three locations in North Carolina (2 replicates at each location) were obtained which represented most of the flue-cured cultivars currently grown in the United States (Table 1). The condensate deliveries from flue-cured cultivars ranged from 23.9 to 31.5 mg/cig. and from 26.8 to 32.9 mg/g of tobacco smoked. Condensate:nicotine ratios ranged from 5.9 to 7.9. This narrow range was understandable because all flue-cured tobacco cultivars in the United States meet minimum standards before release. These standards include nicotine levels, hence most flue-cured cultivars have similar levels. There was a wide range in condensate/cigarette but the range for condensate/g of tobacco smoked was much narrower. Wernsman et al. (13) reported PMI averages for 10 flue-cured cultivars and stated that differences among those cultivars for PMI were small. They concluded that shifts in popularity among cultivars by growers would not drastically change the TPM potential of cured leaf available to manufacturers. They also gave data from a large number of cultivars and classes of tobacco which showed that PMI means were highest for Burley cultivars, followed by dark fire-cured, air-cured, flue-cured, and Maryland cultivars.

Condensate Delivery from Old Lines of Flue-cured, Burley and other Cultivars

Twenty-two cultivars, Tobacco Introductions (TI), and breeding lines were planted in a randomized block design for 2 years at Oxford, N. C. The tobacco was grown and cured as flue-cured tobacco.

The condensate deliveries ranged from 19.7 mg/cig. (Hicks-Mammoth) to 35.8 (TI 1335) (Table 2). Con-

* Reference to a company or product name does not imply approval or recommendation by the United States Department of Agriculture.

Table 1. Condensate and nicotine from commercial flue-cured tobacco cultivars (average of three locations in North Carolina — 1976).

Cultivar	Nicotine / cigarette (mg)	Condensate* / cigarette (mg)	Condensate / g of tobacco smoked** (mg)	Condensate : nicotine
NC 79	4.0	31.5	31.0	7.9
Coker 347	4.0	30.8	32.9	7.7
McNair 1040	3.9	29.7	31.4	7.6
NC 2326	3.7	28.5	30.8	7.7
Speight G-140	3.5	27.5	30.6	7.9
McNair 944	3.5	27.3	29.0	7.8
NC 12	3.8	27.1	30.0	7.1
Speight G-23	4.0	27.0	30.1	6.8
Va. 115	3.8	26.8	31.3	7.1
NC 88	4.2	26.8	29.7	6.4
Coker 298	3.8	26.7	30.3	7.0
Coker 254	3.7	26.1	29.1	7.1
Coker 319	3.4	26.1	31.1	7.7
Coker 411	3.7	25.9	30.3	7.0
NC 98	3.6	25.7	28.3	7.1
NC 95	4.1	25.7	30.6	6.3
Speight G-33	3.9	25.5	27.7	6.5
Speight G-15	4.3	25.3	29.4	5.9
Coker 258	4.0	24.9	29.3	6.2
Speight G-28	3.3	23.9	26.8	7.2
Least sig- nificant difference	p = 0.05 0.5 p = 0.01 0.6	3.5 4.6	4.9 n.s.*	
Mean of cultivars	3.8	26.9	30.0	7.1

* Condensate = TPM — nicotine — H₂O.

** The cigarettes were 85 mm long and smoked to a butt length of 23 mm; therefore, the condensate / g of tobacco smoked was based on the weight of the 62 mm smoked.

+ n.s. = not significant.

condensate / g of tobacco smoked ranged from 26.6 mg/g (Hicks-Mammoth) to 35.2 (Coker 319). When the condensate / g of tobacco smoked was calculated, the range was not as great. Condensate / g of tobacco smoked is a better measurement of the genotype potential for condensate delivery than condensate/cigarette. The condensate : nicotine ratio ranged from 6.3 for TI 1480 to 44.2 for LAFC 53. The test indicated that Maryland 609 condensate delivery was low. Also, Wernsman et al. (13) concluded the PMI was lower for Maryland cultivars.

Effect of Curing on Condensate Delivery Levels of Maryland and Flue-cured Tobacco

Three cultivars were compared: Maryland 609, NC 2326, and Coker 319. Each cultivar was subjected to both air and flue-curing. The tobacco was grown at Whiteville,

Table 2. Values for several measurements of tobacco smoke with varying nicotine and condensate levels (2-year mean).

Tobacco line or cultivar	Nicotine / cigarette (mg)	Condensate* / cigarette (mg)	Condensate / g of tobacco smoked** (mg)	Condensate : nicotine
TI 383	2.3	27.1	30.9	11.8
TI 1335	4.7	35.8	33.2	7.6
TI 1480	3.6	22.7	28.4	6.3
TI 1502	3.9	31.4	30.1	8.1
TI 1503	2.9	25.9	33.1	8.9
Amarello 5	2.6	23.9	29.8	9.2
Gold Leaf	3.0	27.1	31.3	9.1
I 35	2.3	24.5	28.7	10.7
SC 71	2.1	29.1	33.2	13.9
PD 682	2.8	28.1	30.6	10.2
White-Stem-Orinoco	2.7	28.9	32.4	10.7
Greeneville 48	1.7	19.9	27.8	11.7
Hicks-Mammoth	1.9	19.7	26.6	10.4
Coker 187 (Mammoth)	1.6	25.4	32.2	15.9
SC 58	4.0	27.7	30.8	6.9
Coker 139	2.1	27.6	33.5	13.1
LAFC 53	0.6	25.3	29.0	44.2
Burley 21	3.1	23.7	31.6	7.6
NC 95	3.5	26.7	30.1	7.6
Md. 609	2.4	21.6	27.3	9.0
Coker 319	3.2	30.3	35.2	9.5
Speight G-28	2.8	25.0	28.6	8.9
Least sig- nificant difference	p = 0.05 1.1 p = 0.01 1.5	4.8 6.5	4.2 5.7	

* Condensate = TPM — nicotine — H₂O.

** The cigarettes were 85 mm long and smoked to a butt length of 23 mm; therefore, the condensate / g of tobacco smoked was based on the weight of the 62 mm smoked.

N. C., by using the same production practices as for flue-cured, including transplanting, cultivation, fertilization, and sucker control treatment with maleic hydrazide (1). Cigarettes were made from the cured leaf and smoked by the method previously described in this paper.

Condensate/cigarette was lower for air-cured than for flue-cured tobacco. Cigarettes from Maryland 609 delivered less condensate than those from the flue-cured cultivars when they were either air or flue-cured (Table 3). The nicotine in the smoke was related to the total alkaloids in the cured leaf; however, the smoke from Maryland 609 had less nicotine/cigarette than that from either of the flue-cured cultivars. When condensate / g of tobacco smoked was compared there was no difference between cultivars when flue-cured. Also, there was no difference in condensate / g of tobacco smoked for flue-cured culti-

Table 3. Smoke analysis of Md. 609, NC 2326 and Coker 319 tobacco cultivars when flue and air-cured (1).

Curing method	Cultivars	Total alkaloids in the leaf (%)	Nicotine / cigarette (mg)	Condensate* / cigarette (mg)	Condensate / g of tobacco smoked** (mg)	Condensate : nicotine
Flue-cured	Md. 609	2.4	2.3	26.7	30.4	11.6
	NC 2326	2.5	3.0	32.1	29.5	10.7
	Coker 319	2.3	2.8	31.0	30.7	11.1
Air-cured	Md. 609	0.8	0.7	18.6	23.3	26.6
	NC 2326	1.1	1.0	23.9	29.2	23.9
	Coker 319	1.0	0.9	23.3	30.1	25.9

* Condensate = TPM — nicotine — H₂O.

** The cigarettes were 85 mm long and smoked to a butt length of 23 mm; therefore, the condensate / g of tobacco smoked was based on the weight of the 62 mm smoked.

vars, whether air or flue-cured. There was lower condensate / g of tobacco smoked when Maryland 609 was air-cured.

Effect of Burley and Flue-cured Genotypes on Condensate Delivery

Five flue-cured and five Burley cultivars were evaluated at Reidsville, N. C. (5). All lines were grown in single-row plots consisting of 20 competitive plants under flue-cured culture. All plots were hand-primed and flue-

cured. A representative sample of leaves was collected from each plot, midribs were removed and lamina was made into cigarettes.

Statistically significant differences in smoke components were found for seven of the ten traits, but all Burley cultivars were not significantly different from all flue-cured cultivars for any trait (Table 4). Burley cultivars were generally higher in condensate / g of tobacco smoked. There were significant differences among Burley cultivars in condensate / g of tobacco smoked and in condensate : nicotine ratio.

Table 4. Means for smoke components in Burley and flue-cured tobacco cultivars at Reidsville, North Carolina (4).

Cultivar	Nicotine / cigarette (mg)	Condensate* / cigarette (mg)	Condensate / g of tobacco smoked** (mg)	Condensate : nicotine
<i>Flue-cured</i>				
Virginia Gold	3.7cd ⁺	29.5	26.8abc	8.0abcd
Bottom Special	2.5a	25.3	23.9ab	10.1b
Hicks Broadleaf	3.9cd	30.4	25.9abc	7.8abcd
Coker 139	2.8ab	26.3	23.7ab	9.4cd
Coker 140	3.0abc	27.2	24.8abc	9.1cd
Mean for flue-cured	3.2	27.8	25.0	8.7
<i>Burley</i>				
Virginia B 29	4.2d	28.8	32.6c	6.9ab
Burley 49	3.7cd	21.0	22.5a	5.7a
Ky. 14	3.6bcd	26.8	30.6bc	7.4bcd
Ky. 12	3.5bcd	25.4	29.8abc	7.3abc
Ky. Experimental 42	4.1d	24.4	31.2bc	6.1ab
Mean for Burley	3.8	25.5	29.4	6.7

* Condensate = TPM — nicotine — H₂O.

** The cigarettes were 85 mm long and smoked to a butt length of 23 mm; therefore, the condensate / g of tobacco smoked was based on the weight of the 62 mm smoked.

⁺ Means followed by different letters are significantly different at $p = 0.05$ by Duncan's new multiple range test.

Condensate / g of tobacco smoked was a better parameter than condensate/cigarette for studying genetic variability for condensate delivery, because of variations in physical traits of cigarettes. All of the flue-cured cultivars were lower than Burley cultivars in delivery of condensate / g of tobacco smoked. Burley 49 was an exception with condensate delivery equal to that of flue-cured cultivars.

Comparison of Condensate Delivery to Genetically Altered Nicotine Levels

In 1967, a project was initiated at the Oxford Tobacco Research Laboratory to transfer the genetic trait for low nicotine into several commercial cultivars of flue-cured tobacco and to determine the influence of this trait on other characteristics (2). The low nicotine character was transferred into 10 flue-cured cultivars by the backcross method. The cultivars used as recurring parents were: Hicks, Va. 115, Coker 258, McNair 12, NC 2326, Coker 298, SC 71, SC 58, NC 95 and Coker 139. Five low-nicotine lines in each of these families were produced and tested at three locations in North Carolina in 1973 and 1974. In general, the low-alkaloid lines delivered slightly lower condensate than did their parents (Table 5). On an average, this was 4 mg of condensate/cigarette; however, when the condensate / g of tobacco smoked was calculated, the differences were not as large. Therefore, condensate delivery did not decrease appreciably when nicotine levels were decreased but the condensate : nicotine ratio increased considerably. The use of low-nicotine lines to reduce condensate delivery may not be desirable.

Particulate Matter Index of Tobacco Introductions and Cultivars

One hundred and eighty lines and cultivars were grown at Oxford, North Carolina, in 1977 and 1978. The lines represent a wide range of material; however, most were selected from the Tobacco Introduction (TI) group maintained by the U.S. Department of Agriculture. Extreme variations in growth characteristics were sought. The material was replicated twice in both years and PMI and percent total alkaloids (TA) were determined on cured leaf.

There was considerable variation for PMI between years. The average index ranged from 202 for PI 418595 to 285 for TI 426 (Table 6). There appeared to be an association between percent total alkaloids in the leaf and the PMI. For example, *Nicotiana rustica* had the highest level of total alkaloids (8.78 %) with a PMI of 279, whereas PI 418597 had an alkaloid content of 1.97 % and a PMI of 230. In a comparison of cultivars and classes of tobacco for their PMI, Ky. 16 (Burley) had 252, Conn. Shade (cigar wrapper) had 270, Va. 310 (dark fire-cured) had 273, and Turkish cultivars were all high. The flue-cured lines were lower; NC 2326 and NC 95 had 235 and 238, respectively; Coker 139 was lowest of the flue-cured with 226 while SC 58 was somewhat higher with 240. Maryland 609 had 234.

Table 5. Comparison of five low-alkaloid lines with their recurrent parent as regards their average smoke composition (2).

Recurrent parent and line	Nicotine / cigarette (mg)	Condensate* / cigarette (mg)	Condensate / g of tobacco smoked** (mg)	Condensate : nicotine
Hicks	3.5	42.4	38.7	12.1
Low-alkaloid lines ⁺	0.9	37.8	42.4	42.0
Va. 115	3.5	41.0	43.2	11.7
Low-alkaloid lines ⁺	0.7	35.5	42.3	50.7
Coker 258	3.3	44.4	50.7	13.5
Low-alkaloid lines ⁺	0.9	39.3	47.2	43.7
McNair 12	3.2	38.5	40.6	12.0
Low-alkaloid lines ⁺	0.7	36.4	40.5	52.0
NC 2326	3.2	43.2	47.3	13.5
Low-alkaloid lines ⁺	0.5	37.7	43.0	75.4
Coker 298	3.6	38.6	42.3	10.7
Low-alkaloid lines ⁺	0.8	36.8	41.3	46.0
SC 71	3.3	40.2	45.9	12.2
Low-alkaloid lines ⁺	0.6	32.5	42.4	54.2
SC 58	4.3	41.0	46.8	9.5
Low-alkaloid lines ⁺	0.8	37.8	43.5	47.3
NC 95	3.3	38.6	39.2	11.7
Low-alkaloid lines ⁺	0.8	37.5	43.9	46.9
Coker 319	2.8	39.7	43.5	14.2
Low-alkaloid lines ⁺	0.5	36.2	40.6	72.4
Mean parent	3.4	40.8	43.8	12.0
Mean low-alkaloid lines	0.7	36.8	42.7	52.6

* Condensate = TPM — nicotine — H₂O.

** The cigarettes were 85 mm long and smoked to a butt length of 23 mm; therefore, the condensate / g of tobacco smoked was based on the weight of the 62 mm smoked.

⁺ Values for low-alkaloid lines are means of five lines in each family.

Lowering the Condensate : Nicotine Ratio

Data from previous tests suggested that the best way to lower the condensate : nicotine ratio is by increasing the nicotine level and, at the same time, maintaining or lowering condensate levels. High nicotine lines were selected from the germplasm bank maintained by the Oxford Tobacco Research Laboratory, to test the condensate : nicotine ratio. In 1979, these lines and several others were planted. In that test, yield and other agronomic characteristics were not considered. The ratio of condensate : nicotine ranged from 5.3 (TI 717) to 75.0 for one of the low-nicotine lines (Table 7). *Nicotiana rustica* which had a ratio of 7.1 was also included in the test.

Table 6. Particulate matter Index (PMI) on certain lines of tobacco (Oxford, North Carolina).

Line	Total alkaloids (%)	PMI (mg/g)	Line	Total alkaloids (%)	PMI (mg/g)
TI 7	5.5	255	TI 719	6.2	254
TI 79	6.0	273	TI 720	6.2	255
TI 85	6.6	260	TI 729	6.3	270
TI 87	5.5	258	TI 731	7.4	279
TI 88	6.4	258	TI 732	5.3	267
TI 92	5.9	262	TI 748	6.3	259
TI 93	5.1	264	TI 752	6.3	254
TI 94	5.5	250	TI 764	5.5	252
TI 97	4.1	244	TI 767	4.2	247
TI 125	6.3	275	TI 780	6.0	254
TI 135	6.0	255	TI 782	6.0	253
TI 154	6.4	252	TI 799	5.7	267
TI 164	6.0	261	TI 804	6.0	272
TI 173	5.4	255	TI 814	7.3	273
TI 177	6.1	265	TI 820	6.2	248
TI 180	6.1	267	TI 821	6.8	270
TI 184	5.7	261	TI 822	5.7	262
TI 186	4.5	235	TI 824	6.3	262
TI 187	4.9	244	TI 874	5.7	274
TI 205	7.1	248	TI 875	6.5	261
TI 233	7.5	271	TI 916	7.1	273
TI 285	5.4	268	TI 918	7.7	283
TI 307	6.4	244	TI 935	5.1	256
TI 310	6.4	274	TI 937	7.8	283
TI 328	7.0	266	TI 942	5.7	258
TI 340	6.2	246	TI 960	4.4	255
TI 366	6.5	267	TI 968	5.3	270
TI 372	5.9	256	TI 983	6.1	249
TI 375	6.9	255	TI 990	6.5	275
TI 380	5.9	257	TI 1073	5.0	253
TI 401	5.8	256	TI 1097	5.3	267
TI 421	5.4	266	TI 1110	5.5	248
TI 422	6.3	263	TI 1123	7.9	253
TI 423	6.3	272	TI 1125	6.5	257
TI 425	7.6	278	TI 1229	7.0	256
TI 426	7.6	285	TI 1239	5.6	253
TI 432	5.8	271	TI 1241	6.2	258
TI 433	6.8	279	TI 1242	6.3	258
TI 451	5.3	246	TI 1253	7.1	263
TI 453	6.2	273	TI 1269	6.2	266
TI 455	6.4	282	TI 1271	6.2	269
TI 463	4.2	251	TI 1286	5.8	263
TI 464	7.4	273	TI 1299	7.4	268
TI 483	6.3	266	TI 1301	7.8	276
TI 487	5.3	258	TI 1302	8.0	283
TI 489	7.1	284	TI 1303	5.2	263
TI 490	4.4	252	TI 1308	7.4	272
TI 492	5.0	253	TI 1309	7.1	258
TI 502	5.0	245	TI 1311	7.5	265
TI 509	6.1	268	TI 1313	7.1	265
TI 536	6.3	272	TI 1321	5.4	234
TI 538	4.9	259	TI 1335	6.3	266
TI 540	6.6	279	TI 1347	5.2	240
TI 553	5.9	268	TI 1381	6.1	253
TI 556	6.1	281	TI 1420	6.7	266
TI 589	6.2	283	TI 1453	6.4	259
TI 592	5.9	271	TI 1495	6.7	268
TI 604	6.2	268	TI 1496	5.9	251
TI 683	7.5	270	Coker 213	4.5	248
TI 717	6.7	262	Oxford 1-181	5.1	250

Table 6 (cont'd.)

Line	Total alkaloids (%)	PMI (mg/g)	Line	Total alkaloids (%)	PMI (mg/g)
Oxford 2	4.8	256	Va. 310	5.6	273
PD 114	5.4	261	Kavalia	4.8	263
PD 468	5.1	257	Smyrna	4.8	266
SC 58	4.8	240	Xanthi-Yaka	5.8	270
Smith TI 79A	6.3	271	Samsun	7.1	282
Smith 79X	7.1	268	Xanthi (Smith)	7.0	264
Vesta 64	4.1	241	Xanthi (Mitchell)	7.0	274
White Mammoth	3.6	241	Xanthi-N	6.2	268
Gr 44	4.0	247	C-20	3.0	246
Kelly Burley	4.7	257	<i>N. Rustica</i> Brasilia	8.8	279
Ky. 16	4.9	252	C-21	2.3	229
DSTC	5.0	254	C-22	2.0	228
Bell B	4.8	253	PI 418592	2.8	242
Bell C	5.3	260	PI 418593	2.0	217
CG 1	6.2	255	PI 418594	3.8	235
CG 2	5.1	247	PI 418595	2.2	202
CW 3 (FL)	5.7	268	PI 418596	3.1	227
CW 3 (WSL)	5.3	261	PI 418597	1.9	230
Conn. Bdl.	5.6	256	PI 420731	2.5	245
Conn. Shade	6.6	270	I 13	3.1	252
Conn. 49	4.5	253	I 14	6.0	270
Fla. 301	5.6	251	I 62	5.3	250
Conn. 911	6.1	251	I 66	3.8	263
M-2	5.0	241	NC 2326	3.4	235
56-96	5.4	250	NC 95	4.2	238
CW 396	5.4	254	PY 10	3.4	241
CW 658	6.0	257	Md. 609	4.0	234
Little Hill	4.8	255	Coker 139	3.1	226
Hav. K2-2X	6.6	250	TI 1112	4.1	244
Hav. 263	6.1	266			

SC 58, a flue-cured cultivar with a high level of nicotine, had a ratio of 8.9.

The condensate and nicotine deliveries from *N. rustica* were generally higher than those from *N. tabacum* and the condensate : nicotine ratio was generally lower for the smoke from *N. rustica* than that for the smoke from most flue-cured tobacco cultivars. The gene(s) responsible for production of nicotine in *N. rustica* were transferred into *N. tabacum*. Unfortunately, the nicotine levels in the derived lines were not much different from those already in *N. tabacum*. A series of crosses was made between the derived lines and cultivars of *N. tabacum*. In most instances, the levels of nicotine were not higher than the *N. tabacum* parent. From one series of crosses involving *N. rustica*-derived lines and SC 58, however, high levels of nicotine were obtained. The levels in general were about 1.00 % total alkaloids higher than SC 58.

Several of the derived lines were grown in a replicated test in 1979 at two locations in North Carolina. All of the lines had higher nicotine levels than SC 58 but lower than *N. rustica* (Table 8). The condensate delivery / g of tobacco smoked was lower for the lines when compared

with SC 58 and all of them gave a condensate : nicotine ratio lower than SC 58. The indications are that progress is being made in lowering the condensate : nicotine ratio in this material.

One hindrance to lowering condensate delivery in tobacco by plant breeding is the procedure for assaying large numbers of samples. The PMI method tends to alleviate this, but a better, faster method is needed. A multiple regression technique involving selected chemical analyses of cured leaf may offer an additional method. Williamson and Chaplin (14) reported a method for predicting condensate levels by multiple regression procedures by using data from various chemical determinations on the cured leaf. Chemicals determined were: petroleum ether extract, alcohol-chloroform extract, wax, holocellulose, total alkaloids, total nitrogen, alpha amino nitrogen, polyphenols, ash, reducing sugars, and starch. A high level of precision in predicting the condensate deliveries was obtained by using data from seven of the chemical constituents. Data from as few as four chemical constituents of the leaf were useful in developing a prediction equation for the estimation of condensate in tobacco smoke.

Table 7. Smoke constituents of certain tobacco lines (Oxford, North Carolina).

Line or cultivar	Nicotine / cigarette (mg)	Condensate* / cigarette (mg)	Condensate / g of tobacco smoked** (mg)	Condensate : nicotine
TI 186	4.3	39.2	49.9	9.1
TI 205	5.2	64.7	55.5	12.4
TI 233	8.1	45.6	45.9	5.6
TI 328	5.7	44.0	41.3	7.7
TI 340	5.4	44.0	40.8	8.1
TI 375	7.2	44.7	45.0	6.2
TI 425	5.4	44.2	48.0	8.2
TI 451	3.6	34.3	36.7	9.5
TI 464	6.4	50.5	53.2	7.9
TI 502	5.5	44.6	55.5	8.1
TI 717	7.6	40.4	42.6	5.3
TI 752	5.9	47.7	53.6	8.1
TI 814	6.5	45.9	48.3	7.1
TI 1241	6.8	46.2	53.7	6.8
TI 1299	6.5	46.8	50.9	7.2
TI 1308	6.1	52.4	47.9	8.6
TI 1309	5.9	46.8	44.2	7.9
TI 1311	6.6	46.6	45.6	7.1
TI 1313	6.9	34.7	41.7	5.0
TI 1420	5.8	36.1	42.6	6.2
Smith 79X	6.2	51.2	50.9	8.3
PI 418593	2.9	39.6	37.1	13.7
PI 418594	5.7	36.2	43.5	6.4
PI 418596	3.9	38.2	36.9	9.8
PI 420731	5.0	44.1	42.5	8.8
NC 2326	5.3	41.3	41.6	7.8
NC 95	4.8	35.6	39.4	7.4
PY 10	5.5	38.9	41.6	7.1
Md. 609	4.0	28.3	38.0	7.1
Coker 139	3.2	37.6	39.1	11.8
PI 418595	3.6	36.1	38.6	10.0
SC 58	5.0	44.3	44.6	8.9
Speight G-28	3.8	33.4	38.8	8.8
Pale Yellow Mammoth	3.8	37.2	43.2	9.8
Coker 187 (Mammoth)	3.2	41.6	50.9	13.0
LAFC 53	0.8	28.8	28.8	36.0
LA 11	0.7	32.1	32.1	45.9
LA 21	0.7	27.5	31.4	39.3
LA 38	0.6	29.3	33.5	48.8
LA 39	0.4	29.8	36.4	75.0
LA 46	1.0	31.6	29.5	31.6
LA 56	0.6	27.9	32.7	47.0
<i>N. Rustica</i> Brasilia	6.7	47.8	49.6	7.1

* Condensate = TPM — nicotine — H₂O.

** The cigarettes were 85 mm long and smoked to a butt length of 23 mm; therefore, the condensate / g of tobacco smoked was based on the weight of the 62 mm smoked.

CONCLUSIONS

1. Condensate deliveries among lines of tobacco varied with the environment, cultural practices, and the weather conditions under which the tobacco was produced.

Table 8. Comparison of condensate and nicotine levels among standard tobacco cultivars and *N. rustica*-derived lines.

Cultivar or line	Nicotine / cigarette (mg)	Condensate* / cigarette (mg)	Condensate / g of tobacco smoked** (mg)	Condensate : nicotine
129	5.6	36.2	35.9	6.5
131	5.1	26.4	30.6	5.2
132	5.0	27.8	34.0	5.6
133	5.2	29.8	35.2	5.7
134	5.0	26.7	31.0	5.3
135	5.4	30.2	36.9	5.6
SC 58	4.7	32.7	37.6	7.0
NC 95	4.1	34.1	33.6	8.3
<i>N. rustica</i> Brasilia	6.7	43.8	45.4	6.5

* Condensate = TPM — nicotine — H₂O.

** The cigarettes were 85 mm long and smoked to a butt length of 23 mm; therefore, the condensate / g of tobacco smoked was based on the weight of the 62 mm smoked.

2. Condensate / g of tobacco smoked is a better index than condensate/cigarette for evaluation of condensate delivery of breeding lines.

3. The range of condensate deliveries and the condensate : nicotine ratios for present flue-cured cultivars are small.

4. When classes of tobacco were compared for condensate deliveries, Burley was high and Maryland low.

5. Flue-cured generally delivered less condensate than Burley.

6. Low-nicotine tobaccos do not have the potential for lowering condensate delivery, because of their high condensate : nicotine ratios.

7. The particulate matter index (PMI) may be used to screen large numbers of samples; however, a smoke test is required prior to making a final judgment as to condensate deliveries.

8. The PMI appeared to correlate better with condensate / g of tobacco smoked than with condensate/cigarette.

9. To alter the condensate : nicotine ratio the high-nicotine lines appeared most promising.

10. Condensate deliveries from tobacco are controlled by multiple genetic factors. Breeding procedures which accumulate large numbers of genes should be the best method to use. This does not preclude the use of other methods such as the pedigree, dihaploid and interspecific hybridization.

11. For the breeder to develop lines that deliver low condensate and have good smoking flavor, it will be necessary, simultaneously, to select for certain flavor

compounds. More research is needed in this area so that breeders will be able to select for certain flavor-related constituents.

12. Condensate and nicotine deliveries appear to be associated; therefore, selections for both nicotine and condensate are necessary in order to modify the condensate : nicotine ratio.

13. More evaluation, such as their smokeability, is needed on lines of tobacco with high nicotine levels.

SUMMARY

Condensate deliveries from cigarettes can be reduced by manufacturers in various ways. Lines or cultivars of tobacco can also be developed whose cured leaf, upon pyrolysis, delivers less condensate in the smoke. Since there appears to be an association between condensate and nicotine in smoke, the condensate : nicotine ratio is important to the development of lines of tobacco that deliver low condensate levels. Experiments were conducted to evaluate the potential for genetically controlling condensate delivery in cigarette smoke and data are presented. In general, when comparing the condensate delivery potential for different classes of tobacco, Burley delivered higher condensate values followed by dark fire-cured, dark air-cured, flue-cured and Maryland cultivars. In selecting genotypes for lowering condensate deliveries, the condensate / g of tobacco smoked is a better index than condensate/cigarette. In evaluating low-alkaloid tobaccos, the condensate delivery did not decrease appreciably as the total alkaloids were decreased. On an average, the decrease was about 4 mg of condensate/cigarette when compared with normal-alkaloid types but the condensate : nicotine ratio increased greatly.

The ratio of condensate : nicotine was lowered when lines high in nicotine were produced. In one test reported, the ratio of condensate : nicotine ranged from 5.3 (TI 717) to 75.0 for a low-nicotine line. *N. rustica* had higher nicotine than *N. tabacum* cultivars and a lower condensate : nicotine ratio. The gene(s) responsible for the production of nicotine in *N. rustica* were transferred into *N. tabacum* and some of the derived lines had a nicotine content about 1% higher than SC 58, the highest-nicotine cultivar, or flue-cured tobacco available. The condensate delivery / g of tobacco smoked was lower for these lines when compared with SC 58. All of the lines tested gave a condensate : nicotine ratio lower than SC 58. The data showed that condensate deliveries from tobaccos vary with the environment, cultural practices and the weather conditions under which the tobacco is produced. To make progress in breeding for lower condensate delivery in tobacco, it is necessary to assay large numbers of samples and methods for doing this were discussed. To breed low-condensate delivery lines with good smoking flavor, it will be necessary, simultaneously, to select for certain flavor compounds. More research is needed on flavor chemicals of tobacco and their relationship to condensate.

ZUSAMMENFASSUNG

Die sich beim Abrauchen von Zigaretten bildende Kondensatmenge kann vom Zigarettenhersteller auf verschiedene Weise verringert werden. Es können aber auch Tabaklinien oder -sorten mit Blattgut gezüchtet werden, das bei der Pyrolyse nach der Trocknung weniger Rauchkondensat entstehen läßt. Da zwischen dem Kondensat und dem Nikotingehalt des Rauches ein Zusammenhang zu bestehen scheint, ist für die Züchtung von Tabaklinien mit geringer Kondensatbildung das zwischen diesen beiden Komponenten bestehende Mengenverhältnis von Bedeutung. Die Autoren untersuchten experimentell, in welchem Maße die Kondensatmenge des Zigarettenrauches durch genetische Charakteristika des Tabaks beeinflusst werden kann. Im allgemeinen zeigte ein Vergleich der in den verschiedenen Tabakgrundtypen möglichen Kondensatausbeuten, daß Burley-Tabak höhere Kondensatwerte hatte als dunkle „fire-cured“-, dunkle „air-cured“- „flue-cured“- und Maryland-Tabake. Bei der Selektion von Genotypen zum Zweck der Züchtung von Tabaksorten mit verminderten Kondensatwerten ist die Kondensatmenge je Gramm verbrannten Tabaks ein besserer Gradmesser als die Kondensatmenge je Zigarette. Bei der Untersuchung von Tabaken mit niedrigem Alkaloidgehalt wurde beobachtet, daß eine Verminderung des Gehaltes an Gesamtalkaloiden im Tabak zu einem nur unerheblichen Rückgang der Kondensatausbeute führte. Im Vergleich zu Tabaksorten mit normalem Alkaloidgehalt belief sich dieser Rückgang im Durchschnitt auf etwa 4 mg Kondensat je Zigarette, wobei das Verhältnis zwischen Kondensat- und Nikotinmenge jedoch erheblich anstieg.

Bei Zuchtlinien mit hohem Nikotingehalt zeigte sich ein Rückgang des Kondensat/Nikotin-Verhältnisses. Dieser Zahlenwert lag in einem Versuch zwischen 5,3 (TI 717) und 75,0 bei einer Linie mit niedrigem Nikotingehalt. *Nicotiana rustica* hatte höhere Nikotinwerte und ein niedrigeres Kondensat/Nikotin-Verhältnis als *Nicotiana tabacum*. Das Gen bzw. die Gene, die für die Nikotinbildung in *N. rustica* verantwortlich sind, wurden auf *N. tabacum* übertragen mit dem Ergebnis, daß einige der daraus entstandenen Linien einen um etwa 1% höheren Nikotingehalt hatten als SC-58-Tabak, die Sorte mit dem höchsten Nikotingehalt, oder als vergleichbarer „flue-cured“-Tabak. Im Vergleich zum SC-58-Tabak war bei allen diesen Linien die Kondensatmenge je Gramm verbrannten Tabaks und das Kondensat/Nikotin-Verhältnis niedriger. Die Ergebnisse zeigen, daß die Kondensatausbeute von Tabaken je nach den angewandten Anbauverfahren und den während des Wachstums herrschenden Umweltbedingungen und Witterungsverhältnissen verschieden ist. Zur Erzielung von Fortschritten bei der Züchtung von Tabak mit geringer Kondensatbildung ist die Untersuchung einer großen Anzahl von Proben erforderlich; mögliche Untersuchungsmethoden werden diskutiert. Um zusätzlich ein gutes Raucharoma solcher Tabake zu erhalten, ist es notwendig, auch nach bestimmten Aromastoffen zu selektieren. Die Aromaverbindungen des Tabaks und deren Verhältnis zum Rauchkondensat müssen noch mehr erforscht werden.

Les quantités de condensats se constituant lors du fumage, peuvent être réduites de différentes manières par les fabricants. Mais on peut cultiver des lignées et types de tabac présentant des feuilles, qui une fois sèches, donnent moins de condensats lors d'une pyrolyse. Comme il semble exister une corrélation entre la teneur en nicotine et la formation de condensats dans la fumée, le rapport condensat/nicotine est important pour la culture de lignées de tabac présentant de plus petites quantités de condensat. Les auteurs ont cherché à déterminer de manière expérimentale dans quelle mesure la quantité de condensat contenue dans la fumée de cigarettes peut être influencée par les caractéristiques génétiques du tabac. Une comparaison entre les différents types de tabac a montré que le tabac Burley présentait de plus fortes quantités de condensat que, par ordre décroissant, les tabacs «fire-cured» noir, «air-cured» noir, «flue-cured» et du Maryland. Pour la sélection des génotypes en vue de la culture de tabacs à teneur en condensat réduite, la quantité de condensat par gramme de tabac brûlé est un meilleur indice de référence que la quantité de condensat par cigarette. Lors de l'étude de tabacs à plus faible teneur d'alcaloïde, on a constaté qu'une réduction de leur teneur en alcaloïdes totaux n'aboutit qu'à une baisse insignifiante de la production de condensat. Par comparaison avec les types de tabac à teneur en alcaloïde normale, cette baisse s'élevait en moyenne à 4 mg de condensat par cigarette; toutefois, le rapport condensat/nicotine a augmenté considérablement.

Le rapport condensat/nicotine s'est révélé plus bas pour les lignées à haute teneur en nicotine. Dans l'un des tests, ce rapport s'est situé entre 5,3 (TI 717) et 75,0 pour une lignée à faible teneur en nicotine. Le type *Nicotiana rustica* a présenté une plus forte teneur en nicotine et un plus faible rapport condensat/nicotine que le type *Nicotiana tabacum*. Le gène ou les gènes responsables de la constitution de la nicotine dans le *N. rustica* ont été transférés sur le *N. tabacum*, ceci ayant pour conséquence une augmentation de 1% de la teneur en nicotine de certaines lignées ainsi obtenues, par rapport au tabac SC58, sorte ayant la plus forte teneur en nicotine, ou au tabac «flue-cured» qui s'en approche. Pour toutes ces lignées les rapports condensat/g de tabac brûlé et condensat/nicotine étaient inférieurs à ceux constatés sur le SC58. Les résultats de l'étude font également apparaître que la production de condensat dans les tabacs varie selon les modes culturaux appliqués et selon l'environnement et le climat. Si l'on veut progresser dans la culture de tabac présentant une plus faible formation de condensat, il est indispensable de procéder à l'étude d'un grand nombre d'échantillons. Les méthodes possibles sont discutées. Si l'on désire en outre que ces tabacs aient une fumée de bonne qualité aromatique, il est nécessaire de les sélectionner d'après leurs constituants aromatiques. Il conviendra d'approfondir encore l'étude des substances aromatiques du tabac ainsi que leurs relations avec le condensat.

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